Morphometric Relationships and Catch Composition of Wobbegong Sharks (Chondrichthyes: *Orectolobus*) Commercially Fished in New South Wales, Australia

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Wobbegongs (Orectolobiformes) are commercially targeted in New South Wales, Australia. Catches have declined approximately 60% in a decade, leading to concerns over the fishery's sustainability. However, length and weight composition of the catch is unknown as carcasses are trunked (i.e. beheaded and eviscerated) before landing. We provide parameters for length–length, weight–weight and weight–length relationships to convert carcass length and carcass weight measurements to total lengths and total weights used in fisheries assessments. Neonates and small juveniles were conspicuously absent in the length-frequency distributions of all three species, suggesting the potential existence of nursery areas not available to the commercial fishery.

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KEYWORDS: commercial fishery, morphometric relationship, *Orectolobus*, wobbegong.

INTRODUCTION

Three species of wobbegong shark: the spotted wobbegong, *Orectolobus maculatus*, the dwarf ornate wobbegong, *O. ornatus*, and the large ornate wobbegong, *O. halei* (Huveneers 2006) occur in coastal waters off New South Wales (NSW), Australia and are commercially targeted by the Ocean Trap and Line fishery. Wobbegongs have been sold as 'boneless fillets' or 'flake' and their catch has declined from ~150 tonnes in 1990/91 to ~70 tonnes in 1999/00, a decrease of > 50% in less than a decade (Pease and Grinberg 1995; NSW Department of Primary Industries, unpublished data). This decline led to wobbegongs being listed as 'Vulnerable' (in NSW) and 'Near Threatened' (globally) under the World Conservation Union (IUCN) Red List assessment (Cavanagh et al. 2003) and to concerns over the sustainability of the fishery.

Given that many shark species, including wobbegongs, are trunked prior to landing, partial length and carcass weight are usually the only measurements that can be recorded (FAO 2000). Relationships between partial length and carcass weight and their respective total length and total weight are a fundamental requirement for an assessment of the catch composition, and towards the ecologically sustainable management of the fishery.

This study presents length–length, weight–weight, and weight–length relationships for each of the three species caught in the NSW commercial fishery. Catch composition and length-frequency distributions recorded during the study are also presented.

MATERIALS AND METHODS

Wobbegongs were collected from commercial fishers at six locations in NSW (Nambucca Heads, Port Stephens, Newcastle, Terrigal, Sydney and Eden) (Fig. 1). Wobbegongs were caught on setlines with O'Shaughnessy style hooks size 10/O or 12/O, with a 50–100 cm long wire or nylon trace attached to the bottom line by a stainless sharkclip. Hooks were baited with black fish (*Girella tricuspidata*), mullet (*Mugil cephalus*) or Australian salmon (*Arripis trutta*). Lines were set before sunset and hauled at

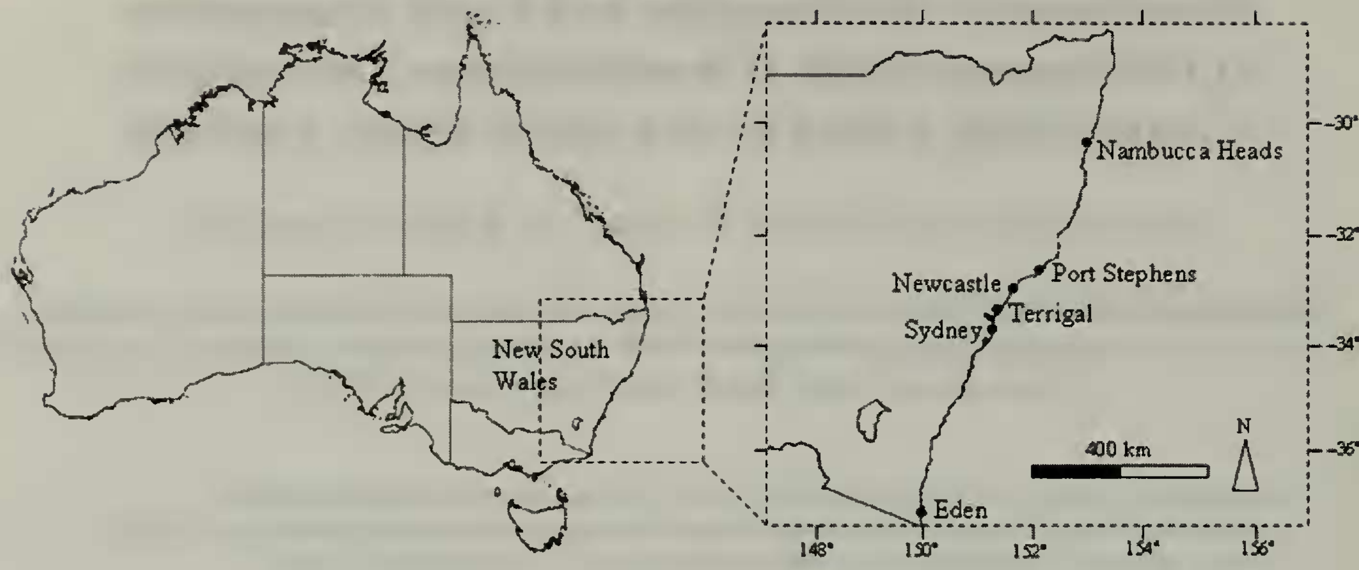

Figure 1. Sampling locations for collection of wobbegongs in New South Wales, Australia

sunrise on the following day.

The species, gender and a series of length measurements were recorded (to the nearest mm) for each shark caught. The length measurements included: total length (TL), snout to anal-fin insertion length (SAL), and partial length from the pectoral-fin origin to the caudal-fin origin (PL). SAL was taken instead of fork length as upper and lower caudal fin lobes of wobbegongs are not discernible. Total weight (TW) and carcass weight (CW) were recorded using spring balances (scale: 100 ± 0.2 kg, 20 ± 0.2 kg, 5 ± 0.1 kg).

Linear regressions of TL on SAL, TL on PL, and TW on CW were determined for each of the three species using data pooled across all sites. Log-transformed data were used for the regressions of TW on TL and CW on PL and corrected for biases caused by natural logarithmic transformation (Beauchamp and Olson 1973). Analyses of covariance (ANCOVA) were used to test for differences between sexes in all regressions. When the slopes and intercepts did not differ significantly between sexes the data were pooled and a common regression determined.

RESULTS

A total of 904 wobbegongs (435 males and 469 females) was collected comprising: 183 male and 202 female *O. ornatus* (combined range 471-1,017 mm TL), 97 male and 88 female *O. maculatus*, (combined range 870-1,575 mm TL), and 155 male and 179 female 334 *O. halei* (combined range 869-2,065 mm TL). Most *O. ornatus* (86.5%) were collected off Nambucca Heads with none caught south of Port Stephens. *Orectolobus maculatus* catches were distributed among Nambucca Heads (26.5%), Port Stephens (30.8%) and Sydney (37.8%), with none caught in Eden. *Orectolobus halei* were caught at all locations, with the majority caught off Sydney (62.6%), and sporadic captures at the remaining locations (Table 1). Neonates (born at ~21 cm for *O. ornatus* and *O. maculatus* and ~30 cm for *O. halei*) and small juveniles were absent in the catches of all three species (Fig. 2).

The conversion parameters estimated are applicable to the size range analysed (Table 1) which covers most of the population size range, with the exceptions of neonates and small juveniles (not caught by the commercial fishery). All regressions were significant with 19 correlation coefficients out of 22 over 0.84 (Table 2 and 3).

The slopes of the regressions of TL on SAL (Table 2) did not differ significantly between the sexes for *O. ornatus* and *O. maculatus* (ANCOVA: $F_{slopes} = 2.17$ and 0.62 respectively, $P > 0.05$), but the intercepts differed significantly between males and females (ANCOVA: $F_{intercepts} = 5.29$ and 11.06 respectively, both $P < 0.05$). The adjusted means showed that male *O. ornatus* and *O. maculatus* had a significantly greater TL for a given SAL compared to females. Similarly, the slopes of the regressions of TL on PL (Table 2) did not differ significantly between the males and females of *O. ornatus* and *O. maculatus* (ANCOVA: $F_{slopes} = 3.06$ and 0.17 respectively, $P > 0.05$). Again, the intercepts of the regressions of TL on PL (Table 2) differed significantly between the sexes (ANCOVA: $F_{intercepts} = 9.24$ and 2.44, $P < 0.001$ and $P < 0.05$, respectively). The adjusted means showed that the male *O. ornatus* and *O. maculatus* had a significantly greater TL for

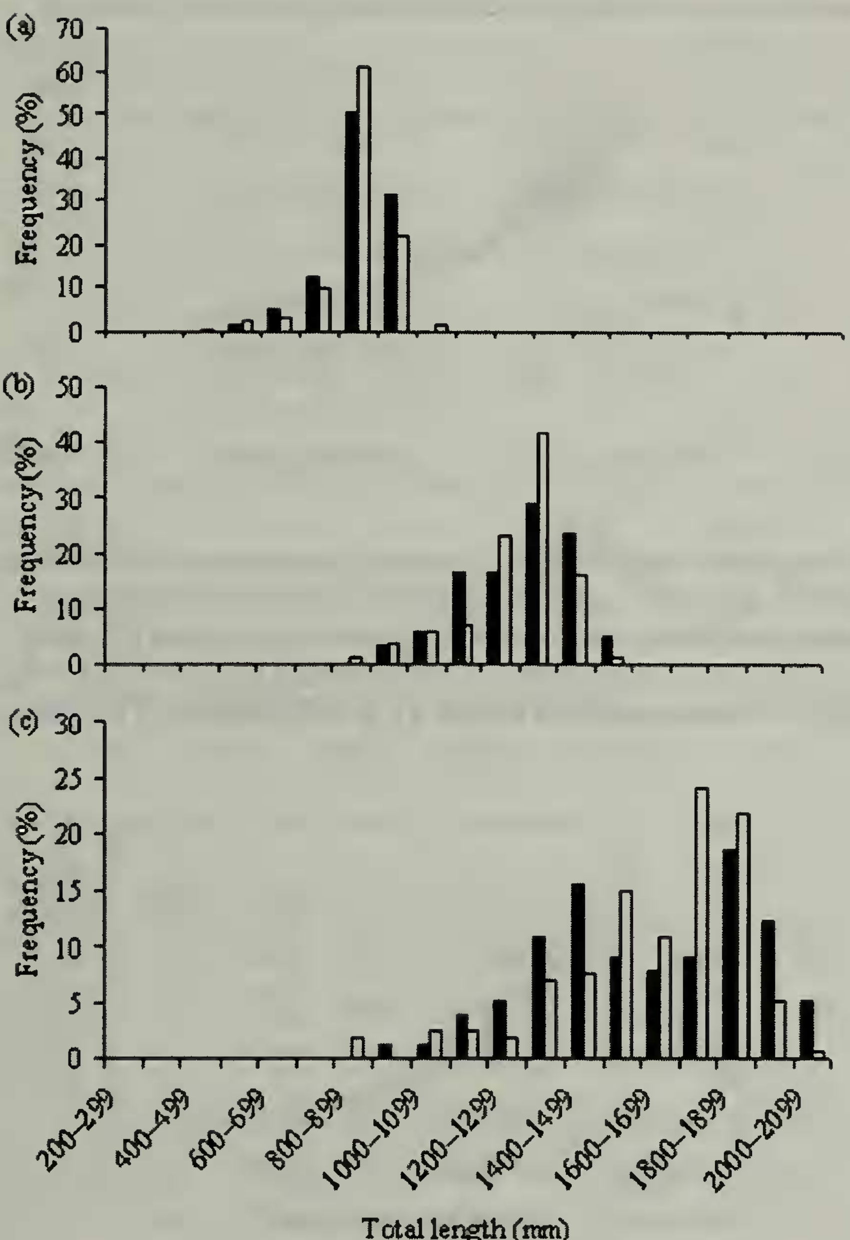

Figure 2. Length-frequency distribution of wobbegongs caught during sampling period for (a) *O. ornatus*, (b) *O. maculatus*, and (c) *O. halei* for males (solid bar) and females (open bar).

a given PL when compared to females. Neither the slopes nor intercepts of the regressions of TL on SAL and TL on PL (Table 2) differed significantly between the sexes for *O. halei* (ANCOVA: TL on SAL: $F_{slopes} = 2.18$ and $F_{intercepts} = 1.57$, both $P > 0.05$; TL on PL: $F_{slopes} = 0.31$ and $F_{intercepts} = 0.40$, both $P > 0.05$).

The slopes of the regressions of TW on TL (Fig. 3 and Table 3) differed significantly between male and female *O. ornatus* (ANCOVA: $F_{slopes} = 6.62$, $P < 0.05$) with weight increasing at a faster rate than in females. In contrast, slopes of the regressions of TW on TL (Table 3) for male and female *O. maculatus* and *O. halei* did not differ significantly (ANCOVA: $F_{slopes} = 0.32$ and 0.04 respectively, both $P > 0.05$), but the intercepts were significantly different between the sexes (ANCOVA: $F_{intercepts} = 20.20$ and 5.49, $P < 0.001$ and $P < 0.05$, respectively). The adjusted means showed that females of *O. maculatus* and *O. halei* had a significantly greater TW for a given TL when compared to males.

Neither the slopes nor intercepts of the regressions of CW on PL (Table 3) differed significantly between the sexes for *O. ornatus*, *O. maculatus* and *O. halei* (ANCOVA: $F_{slopes} = 1.95$, 2.15 and 1.15; $F_{intercepts} = 0.01$, 0.04 and 0.60; all $P > 0.05$ for *O. ornatus*, *O. maculatus* and *O. halei* , respectively).

DISCUSSION

The spatial distribution of wobbegong catches provides an indication of their distribution within NSW waters. Port Stephens was the southern-most location where *O. ornatus* was caught. Although *O. ornatus* have been recorded as far south as Sydney (207 km south of Port Stephens), no *O. ornatus* was caught around Sydney. Museum registered specimens have been collected as far north as the Whitsunday Islands (20° 20'S 148° 54'E, Australian Museum specimen IA 3831), restricting the distribution of *O. ornatus* from tropical to warm temperate waters of eastern Australia. *Orectolobus maculatus* is abundant in central NSW, around Port Stephens and Sydney. *Orectolobus maculatus* is caught in larger numbers in northern NSW than *O. halei* and has been recorded as far north as Gladstone (Kyne et al. 2005). In contrast to *O. halei*, *O. maculatus* was rarely caught around Merimbula and Eden (S. Fantham, pers comm.), restricting its distribution in eastern Australia from tropical to temperate waters. *Orectolobus halei* catches were low in northern NSW and higher around Sydney and Eden, where it was the only species caught during this study. In NSW, *O. halei* is more abundant in temperate waters with abundance decreasing in warm temperate waters. There is apparently a similar trend for *O. halei* collected in Western Australia (WA) (J. Chidlow, pers comm.).

Table 1. Number (with TL size range in mm) of wobbegong caught during June 2003–May 2006

Location	*O. ornatus*	*O. maculatus*	*O. halei*	Total
Nambucca Heads	333 (471–994)	49 (1,160–1,485)	31 (1,175–1,972)	411
Port Stephens	52 (577–1,017)	57 (870–1,440)	10 (1,280–1,875)	119
Newcastle		7 (1,265–1,435)	3 (1,444–1,755)	10
Terrigal		2 (unknown)	8 (1,860–1,930)	10
Sydney		70 (1,055–1,575)	209 (869–2,065)	278
Eden			73 (1,190–1,870)	64
Total	385 (471–1,017)	185 (870–1,575)	334 (869–2,065)	904

Table 2. Relationships between length–length and weight–weight. Estimated parameters (and standard error) from the linear regression analysis to derive the equation Y = a+bX; a and b are parameters; n is sample size; r^2 is square of correlation coefficient; rmse is root mean square error; and P is probability of statistical significance between sex with ns representing P > 0.05, * P < 0.05, ** P < 0.01, *** P < 0.001. TL is total length; SAL is snout to anal-fin insertion length; PL is partial length; TW is total weight; CW is carcass weight.

								P	
Y–X	Species	Sex	n	a (s.e.)	b (s.e.)	r^2	rmse	slope	intercept
TL–SAL	*O. ornatus*	Male	161	44.80 (15.52)	1.16 (0.02)	0.94	19.66	ns	*
		Female	164	71.79 (15.51)	1.12 (0.02)	0.94	21.54		
	O. maculatus	Male	93	26.98 (24.33)	1.22 (0.02)	0.97	25.32	ns	*
		Female	77	41.52 (19.03)	1.20 (0.02)	0.98	16.52		
	O. halei	Combined	236	10.34 (14.17)	1.23 (0.01)	0.98	33.38	ns	ns
TL–PL	*O. ornatus*	Male	113	164.26 (26.42)	1.28 (0.05)	0.86	34.73	ns	***
		Female	124	96.00 (18.76)	1.38 (0.03)	0.93	25.60		
	O. maculatus	Male	63	159.61 (51.08)	1.40 (0.06)	0.90	43.4	ns	*
		Female	60	184.39 (45.98)	1.34 (0.05)	0.91	39.32		
	O. halei	Combined	174	103.97 (23.34)	1.49 (0.02)	0.96	54.63	ns	ns
TW–CW	*O. ornatus*	Combined	73	1.33 (00.14)	1.33 (0.06)	0.87	0.31	ns	ns
	O. maculatus	Combined	93	3.95 (00.75)	1.01 (0.08)	0.61	1.83	ns	ns
	O. halei	Combined	148	1.67 (00.77)	1.53 (0.05)	0.87	3.90	ns	ns

Neonates and small juveniles were rarely caught by commercial wobbegong fishers at any location. Several reasons may account for their absence. Neonates and small juveniles might occupy crevices to avoid predation and forage on small prey living in the crevices. This may provide a physical partitioning of the habitat within a given location. Gear selectivity could also decrease neonate catch because hooks and baits used in the commercial wobbegong fishery are too large. However, gear selectivity is unlikely to explain the absence of larger juveniles because *O. ornatus* of 700–1000 mm TL are commonly caught using the same gear and in the same areas where only a few *O. halei* smaller than 1300 mm TL are caught. It seems more likely that small wobbegongs are not available to the fishery and occur within different

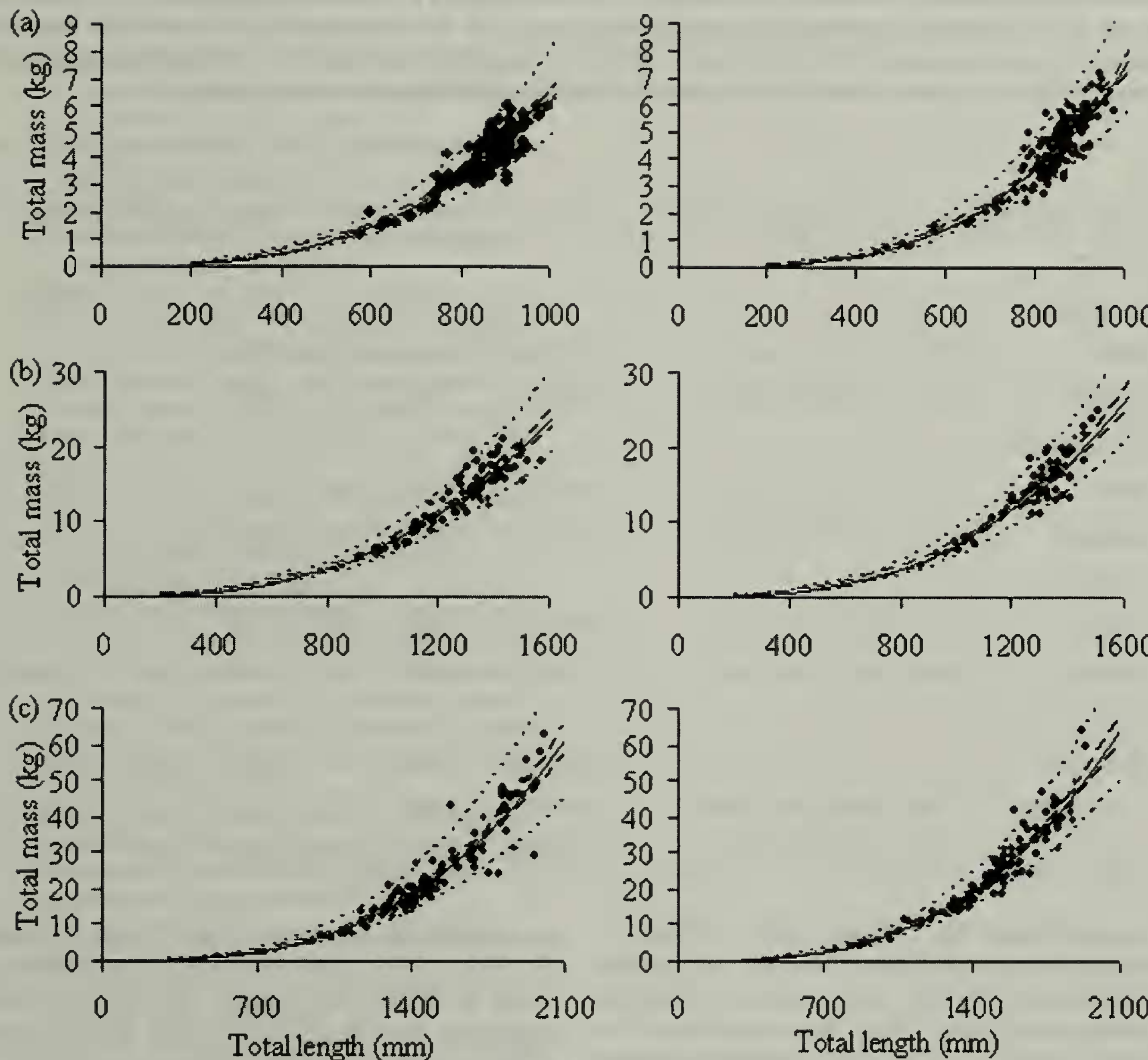

Figure 3. Relationships between total weight and total length of wobbegongs in NSW. Plots of mean total weight against TL (——), with 95% confidence limits (– – –) and 95% prediction intervals (---), for males (left), and females (right) for (a) *O. ornatus*, (b) *O. maculatus*, and (c) *O. halei*. Values for parameters and statistical quantities from regression analysis are given in Table 3.

habitats. Furthermore, a similar study in WA yielded no *O. maculatus* smaller than 900 mm TL and only one *O. halei* (synonym *O. ornatus*) smaller than 1200 mm TL (Chidlow 2003). Size segregation might therefore occur with neonates and small juveniles living in primary and/or secondary nursery areas. Size segregation in habitat use is commonly found in chondrichthyans (e.g. Simpfendorfer 1992), with neonates living in nursery areas for the first weeks, months or years (Heupel and Hueter 2002). Nursery areas are thought to provide neonates and small sharks with increased food availability and/or protection against predators (Heupel and Hueter 2002).

The regression parameters in Tables 2 and 3 are provided for scientists and fisheries managers as an aid to determining size when TL and TW are required but cannot be measured, but where SAL, PL or CW are available. The absence of sex differences in the CW–PL relationships although correlation coefficients are high suggested that somatic growth was similar between males and females (Braccini et al. 2006). However, the regressions of TW on TL differed significantly between males and females with greater body weight in females. Sex-based differences in body weight are often due to discrepancies in the weights of internal organs and are common in

Table 3. Relationships between total weight (TW)–total length (TL) and carcass weight (CW)–partial length (PL). Estimated parameters (and standard error) for the relationships for males and females derived from the equation TW=acTL^b and CW=acPL^b; a and b are parameters; c is the Beauchamp and Olson (1973) correction factor; other parameters and statistical quantities as in Table 2.

							P	
Shark category	n	a (s.e. range) x 10^{-9}	b (s.e.)	c	r^2	rmse	slope	intercept
TW–TL								
O. ornatus							*	***
Males	129	21.1 (10.1–44.1)	2.82 (0.11)	1.008	0.84	3.28		
Females	159	1.81 (0.95–3.46)	3.20 (0.10)	1.010	0.88	4.62		
O. maculatus							ns	***
Males	86	57.4 (26.3–125)	2.69 (0.11)	1.008	0.88	2.88		
Females	73	31.7 (12.8–78.3)	2.78 (0.13)	1.007	0.87	2.64		
O. halei							ns	*
Males	86	73.6 (39.2–138)	2.69 (0.11)	1.008	0.88	2.88		
Females	106	6.52 (3.88–11.0)	3.01 (0.070	1.008	0.95	5.21		
CW–PL								
O. ornatus	26	47 (3.12–709)	2.83 (0.43)	1.008	0.9	0.16	ns	ns
O. maculatus	94	1,090 (405–2,920)	2.38 (0.15)	1.019	0.75	0.15	ns	ns
O. halei	149	69.9 (40.8–120)	2.80 (0.08)	1.013	0.64	0.13	ns	ns

chondrichthyans (e.g. Walker 2005). Differences occur due to the inclusion of pregnant females, and the heavier reproductive organs and liver in females (Stevens and Wiley 1986). In contrast, male *O. ornatus* and *O. maculatus* had significantly greater TL for a given SAL and PL compared to females. The reason for this sex difference is unknown.

Most life history parameters used in fisheries assessments are determined as a function of total length or weight. Wobbegongs landed in the NSW Ocean Trap and Line Fishery are, however, beheaded and eviscerated preventing the measurement of total length and total weight. The regression relationships documented in this study allow estimates of total length and total weight to be obtained from landed carcasses enabling future assessments of the ecological sustainability of the fishery through a more accurate knowledge of the catch composition of this fishery. Although many studies provide relationships between total length and total weight (e.g. Stevens and McLoughlin 1991), we concur with recommendations of the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) (FAO 2000) that future studies should also incorporate the measurement of partial lengths and carcass weight. Only when this is done routinely, will it be possible to estimate, with accuracy, total length and total weight and provide much needed information on the length/weight composition of the catch of shark fisheries.

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